INDIAN NATIONAL COMMITTEE

FOR

INTERNATIONAL UNION OF RADIO SCIENCE

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National Report 1978-80

For presentation at the XX General Assembly
Meeting of URSI, WASHINGTON D.C., August, 1981

INDIAN NATIONAL SCIENCE ACADEMY

1981

REPORT OF
THE INDIAN NATIONAL COMMITTEE FOR INTERNATIONAL UNION OF RADIO SCIENCE
1978–80

For presentation at the XX General Assembly
Meeting of URSI, WASHINGTON D.C., August, 1981

Compiled by

A. P. MITRA
Incoming Chairman
Indian National Committee for URSI

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1981

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FOREWORD

URSI requires, before its General Assembly held at intervals of 3 years, that official members of Commissions of each National Committee prepare national reports of activities in the discipline of that Commission during the last three years in their own country. These reports are then synthesised into an International Volume of PROGRESS IN RADIO SCIENCE published by URSI at the time of the Assembly or soon afterwards. Similar reports were asked for the period 1978-80. From India, reports were prepared and submitted for Commissions, A, D, F, H and J. These will appear in PROGRESS IN RADIO SCIENCE in abbreviated form.

We have, therefore, felt it desirable to publish the Indian reports separately for wide distribution and use. The reports are by no means complete nor do we have reports from all Commissions. Consequently, this volume is to be considered as preliminary.

We are sorry to report that Dr J. S. Shirke who prepared the report for Commission H died in his sleep in Argentina on 21st May, 1981.

Dr A. P. Mitra
Incoming Chairman
Indian National
Committee for URSI

Professor B. R. Rao
Retiring Chairman
Indian National
Committee for URSI

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COMMISSION A

ELECTROMAGNETIC METROLOGY

Prepared by

KAILASH CHANDRA

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REPORT ON ACTIVITIES AT N.P.L., NEW DELHI

THE National Physical Laboratory, New Delhi, India, is responsible for the establishment and maintenance of the 'National Standards' of measurements of all physical parameters and of providing apex level calibration facilities. The existing accuracies of the National Standards for electromagnetic measurements related to some of the parameters are given in Table I. The international traceablility of these standards is established through periodic calibration (every five years) by the International Bureau of Weights and Measures, France or by National Measurement Laboratories of other countries such as U.S.A., U.K., West Germany and Japan.

Facilities for calibration of standard voltage sources, voltage calibrators, standard resistors, precision voltages, current and resistance measuring instruments, standard capacitors and inductors and bridges; A.C. and L.F. measuring instruments, voltage, power and energy measuring instruments; high frequency signal sources, voltage calibrators, attenuators, voltage measuring devices and field-strength meters; high frequency and microwave counters and power meters, microwave signal generators, standard attenuators, phase shifters, impedance standards etc. are available at N.P.L.

The progress at N.P.L. in some of the important areas during the last three years (1979–80) is briefly summarized below.

1. *Time & Frequency Measurements*

Cesium atomic clocks at two far off places in India (Madras and Ahmedabad) have been synchronized *via* French-German Satellite Symphonic-I. Clock synchronization between N.P.L. (India) and PTB (West Germany) has been achieved *via* Satellite Symphonic-I with a precision of better than 10 ns. Symphonic-I was also used for one way coded time transmission and time transfer through direct T.V. broadcast. Some studies on VLF propagation under total solar eclipse conditions have also been made. Intercomparison of Time *via* USNO Travelling atomic clock has also been carried out. UTC (NPL, India) has now been linked with UTC (P.T.B., W. Germany), UTC (NPL, U.K.), U.T.C. (USNO) and UTC (RGO, U.K.) *via* VLF.

Standard signals from 0.1 Hz to 12.4 GHz have been generated using frequency division and phase locking of signal generators and reflex klystrons with cesium atomic clock.

2. *Stabilized Lasers*

He-Ne lasers with frequency stabilization by saturated absorption in iodine (I^{127}) have been fabricated. The frequency stability of these lasers is being studied by measuring the beat frequency between them. Two mode type stabilized He-Ne Lasers with electrical heating of the plasma tube for controlling the cavity length have been fabricated. The stability of these lasers has been found to be 1 part in 10^8. Using this laser as a source, a reversible fringe counting interferometer has been set-up. It is a double-passed Michelson interferometer using two reflectors and a polarizing beam splitter and given 16 counts per wavelength displacement.

3. *Josephson Volt Standard and D.C. Measurements*

A Josephson volt standard using a Nb-Nb point contact has been established. The junction is irradiated by stabilized microwave signal in X-band (frequency stability : few parts in 10^6), and produces constant voltage-current steps at about 1 mv level with a constant current amplitude of 30—70 UA. Standard cell voltage is compared with Josephson voltage using a resistance divider (ratio 1 : 1000) with an overall uncertainty of a few parts in 10^7. Efforts are underway to generate a larger

voltage across the Josephson junction. Investigations on various other types of junction such as solder blob and thin film tunnel junctions have been undertaken.

Physical standards representing the 'volt' and 'ohm' are maintained in the form of banks of standard cells and standard resistors under constant temperature conditions. The measurement system is based on precision potentiometers (1 part in 10^7), direct current comparators (few parts in 10^8), digital d.c. voltmeter, volt-ratio box, tera-ohmmeter, etc.

International intercomparison of D.C. voltage and resistance standards amongst countries of the Asia-Pacific Region is to be carried out soon.

4. *Capacitance & Inductance Standards*

Earlier, a horizontal model of calculable capacitor consisting of tool-steel circular bars and precision mounting assembly kept in vacuum was developed. The value realized with this model is 1 *p*F with an overall uncertainty of 2 parts in 10^6. The precision of transferring this value to 10 *p*F silica, dielectric capacitor using a transformer ratio arm bridge is better than 1 part in 10^7. Now, a vertical model based on N.P.L. (U.K.) design has been established using a large interferometer. This model is expected to give overall uncertainty of the order of 1 part in 10^7 at 0.4 *p*F. A transfer ratio arm bridge with a precision of 1 part in 10^8 has also been fabricated. Scale of capacitance up to 10 UF has been established. Maxwell-Wein bridge for the realization of the unit of inductance from the unit of capacitance has been developed giving an overall uncertainty of 1 part in 10^5.

5. *H.F. and Microwave Attenuation Measurements*

Both audio-substitution and I.F. substitution techniques for H.F. and microwave attenuation measurements up to 12.4 GHz have been established. For audio substitution, inductive voltage divider and a ratio meter are used as standards, and I.F. substitutions techniques are based on waveguide beyond cut-off attenuator (accurancy .001 dB/10 dB and resolution .001 dB) using a laser interferometer with digital display for monitoring the movement of coil inside a precision cylindrical waveguide.

6. *Voltage, Current Power, and Energy Measurements*

Facilities for L.F. Voltage measurements based on multi-junction thermal convertors have been established. Electronic multiplication system with digital display for the measurement of A.C. energy is operational now. New methods of measuring audio-frequency and h.f. voltages utilizing solid state devices have been studied. H.F. voltage standards based on A.T. Voltmeter, thermal convertors and micro-potentiometers have been established. Work on a thin bolometer head to be used as H.F. voltage primary standard is in progress.

A feed-through microwave power measuring transfer standard at 10 GHz has been established. It has traceability to the thin-film bolometer mount of known calibration factor kept in an oil bath.

Transfer standards both thin film baretter type and bolometer type have been developed and d.c. substitute techniques for their calibration have been established (overall uncertainty 0.7 per cent at 10 mW in X-band and 0.7 per cent to 1 in other bands).

Report on some Activities in other Institutions in India

Some work on 'Attracted Disc Type Absolute Voltmeter Using Voltage Balance Techique' has been carried out at Jadavpur University, Calcutta. They are also working on precision capacitance and inductance bridges and direct current comparators for resistance ratio measurements. A two coupler method of permittivity measurements at microwave frequencies has been developed at the Institute of Technology, Banaras Hindu University, Varanasi.

TABLE I

PRESENT STATUS OF ECHELON I STANDARDS OF ELECTRONIC MEASUREMENTS AT N.P.L., NEW DELHI

Parameter	Standards	Range	Accuracy
(1) Frequency	(*i*) Bank of Cs atomic standards		7 parts in 10^{12}
	(*ii*) Rubidiam Standard		1 part in 10^{11}
	(*iii*) Counters locked to atomic standards	up to 18.0 GHz	1 part in 10^{2} to 1 part in 10^{0}
(2) D.C. Voltage	(*i*) Banks of Standard Cadmium cells. Work on Josephson voltage standard in progress	1 volt	2 parts in 10^{7}
	(*ii*) Precision Kelvin-Varley Potentiometers	0.1 V to 2 volt	2 parts in 10^{7} (at 1 volt)
	(*iii*) Volt Ratio Box	2 to 1500 volts	1 part in 10^{4}
(3) D.C. Resistance	(*i*) Bank of one ohm standard resistors	1 ohm	2 parts in 10^{7}
	(*ii*) Fixed Standard Resistors	10^{-5}ohm to 10^{7} ohms	5 parts in 10^{4} to 2 parts in 10^{7} (depending on the value)
	(*iii*) Hamon Resistors	Ratio of 1.100	1 part in 10^{7}
(4) Capacitance	(*i*) Horizontal model of calculable capacitor	1 *p*F	2 parts in 10^{4} (at 1 kHz)
	(*ii*) Silica dielectric standard capacitors	10 *p*F & 100 *p*F	5 parts in 10^{4}
	(*iii*) Air dielectric standard capacitors	10 *p*F, 100 *p*F & 1000 *p*F	5 parts in 10^{4} (at 1 kHz)
	(*iv*) Mica-dielectric standard capacitors	0.01 μF to 1 μF	2-3 parts in 10^{4}
(5) Inductance	Standard Inductors	10 mH, to 100 mH	1 part in 10^{5}
		10 μH, to 1 mH, 1 H	1 part in 10^{4}
(6) A.C. & L.F. Voltage / current	(*i*) Multi-junction thermal convertors	20 Hz to 100 kHz (upto 50 mA)	1 part in 10^{5} to 1 part in 10^{4} (AC/DC transfer error

Parameter	Standards	Range	Accuracy
	(*ii*) Thermo-electric convertor & a set of thermal convertors	250 mV to 1000 V (up to 100 kHz)	5 parts in 10^5 to 5 parts in 10^4
(7) A.C. & L.F. Ratio	Inductive Voltage Divider	20 Hz to 10 kHz	5 parts in 10^8
(8) A.C. Power & Energy	(*i*) Electrodynamic Wattmeters	20 Hz to 120 Hz	0.05% to 0.1%
	(*ii*) Electronic power & energy meter (single phase & 3 phase)	voltage : 10V to 500 V current : 10mA to 10A	0.1%
(9) L.F. Attenuation	Standard 1 kHz attenuator	50 bB	0.007 dB/10 dB
(10) H.F. Voltage	(*i*) Thermo-electric comparator & thermal convertors	250 mV to 100 V (1 MHz to 100 MHz)	0.1% to 1.5%
	(*ii*) Attenuator thermo-element voltmeters	1 V to 100 V (10 MHz to 1 GHz)	1% to 5%
	(*iii*) R.F. Micro-potentiometers	20μV to 500 mV (20 Hz to 1 GHz)	0.01% to 7% (depending upon the voltage & frequency)
(11) H.F. Attenuation	(*i*) Waveguide beyond cut-off attenuator	0—120 dB (10,30,60 & 100 MHz)	0.001 dB/10 dB
	(*ii*) Attenuator calibrator	0—90 dB (10 MHz to 1 GHz)	0.01 dB/10 dB
(12) H.F. Impedance	Sinclaire Bridge (Admittance Conductance)	500 kHz to 10 MHz (G:up to 3000μ mhos B:up to 50000μ mhos)	2%
(13) Microwave Power	(*i*) Standard Waveguide Bolometer-mount (Thin film element)	Up to 10 mW at 10 GHz	±0.37% (Effective efficiency)
	(*ii*) Feed-through transfer standard (bolometer-directional coupler combination)	Up to 100 mW at 10 GHz	±0.7 to 0.8%

(14) Microwave Attenuation	(*i*) Waveguide beyond cut-off attenuator (I.F. Technique)	0—60 dB (30 MHz)	0.005 dB/10 dB
	(*ii*) Attenuation Signal calibrator (I.F. Technique)	0—120 dB	0.01 dB/10 dB
	(*iii*) Standard Attenuator (Auto substitution technique)	0—50 dB	0.007 dB/10 dB
	(*iv*) Standard coaxial & Waveguide attenuators	Up to 60 dB	0.05 dB to 0.1 dB/10 dB
(15) Microwave Impedance	(*i*) Precision quarterwave short circuit (X-band)	—	0.06% in unity reflection coefficient
	(*ii*) Standard Mismatches	1.1 VSWR	±0.005
	(*iii*) Coaxial air line	1.003 VSWR	—
(16) Microwave Phase Shift	Precision moveable short circuits	0.015° at 6.5 GHz 0.1° at 10 GHz	—

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COMMISSION D

PHYSICAL ELECTRONICS

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1978

DC conductivity of bulk amorphous selenium was measured as a function of temperature and electric field. A decrease in activation energy with increase of electric field was observed. The results were interpreted in terms of a mixed, thermally activated and trap limited conduction process.[1] DC conductivity of semiconducting tungston phosphate glasses of different compositions was measured over 100 to 400K. The data were analysed in the light of existing models of polaronic hopping conduction.[2] Thermal activation energy and glass transition temperature were determined from experimental measurements of DC conductivity of As_2S_3-PbS glasses.[3] Effects of Sb and Al implantation on the conductivity of amorphous Ge and Si films were reported. Room-temperature conductivity was found to increase by a factor of 50 to 100 on implantation.[23] DC and AC conductivity and thermoelectric power of evaporated of sputtered films of amorphous Ge and Si were also examined. The variable range hopping theories were found to be inadequate in explaining the experimental data.[25] Negative magnetoresistance of amorphous selenium and tellurium doped selenium was studied; the nagative magnetoresistance was observed to decrease with tellurium doping.[29] Mobility and thermoelectric power of manganous telluride films were studied. The quantities showed peaks around 315 K. The temperature

variation of the quantities was explained in terms of ionized impurity and piezoelectric scattering mechanism.[5]

Free carrier absorption and electron mobility in *n*-type PbTe were theoretically investigated.[4] Possibility of negative diffusivity in semiconductors under a high electric field was explored.[13] Effect of ionised impurity scattering on hot electron diffusion in silicon was also studied.[28] Electron tunnelling in semiconductor heterostructures was investigated.[31] Expressions for dia and paramagnetic susceptibilities of inversion layers were derived; the numerical values were found to be higher than the bulk values.[38]

A new technique for phosphorous doping of silicon float zone crystals using a solid dopant, phosphorous nitride, was reported.[6] Importance of poper materials, bonding surfaces, bonding processes and light control of bonding parameters in avoiding failures in wire bonds was discussed.[7] A simple technique was developed for the closed capsule diffusion of Ga into Si, free from surface damages.[19] Glassy alloy $As^{10}Ge^{15}Te^{75}$ was used to develop a thermal memory switch to sense, control and register any temperature change from 27° to 120°C by application of an AC or DC bias voltage.[20]

Considering a simple linear equivalent circuit of a cavity-mounted Gunn diode, the tuning range was determined by finding the cavity length at X-band frequencies.[8] Spectral intensity of low frequency noise voltage for and insulator with electron-filled traps was calculated.[9] Temperature variations of junction breakdown voltages of zener diodes and transistors were studied.[10] A new scheme for thyristor conduction control was described.[11] Significant developments in the technology of thick film compatible transistors were traced.[12] Possibility of the existence of a transverse diffusion current of minority carriers to the base contact of planar transistors was demonstrated using an electrolytic tank analogue.[14] A quasi-one-dimensional model for estimating DCα of lateral *pnp* transistors was proposed[15]. A computer study was reported on the field and current profiles of silicon X-band symmetrical double-drift IMPATT diodes.[21] Expressions for the noise properties of LO-HI-LO IMPATTS were developed.[32] The existence of a negative resistance in zener diodes when the frequency of

the applied voltage exceeds a critical value was discussed.[33] A method was developed to determine the base recombination lifetime and surface recombination velocity at n-n^+ interface of epitaxial transistors.[34]

Structural defects in the plane of growth of silicon were discussed.[16] Optical and electrical properties of indium selenide were reported.[17] Negative bias instability in thermally grown SiO_2 films on Si was experimentally studied.[18] Secondary emission from high-sensitivity multi-alkali photo cathodes was measured and discussed.[22]

Hall coefficient and conductivity measurements in ZnSe heavily doped with In indicated impurity band conduction even near room temperature.[24] Studies were also made on Hall mobility and free carrier Faraday rotation in degenerate n-GaSb in the temperature range 77–300 K.[26]

An approximate method was developed for investigating the nature of interface exciton modes in a composite spatially dispersive medium.[27]

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THE variation of thermal conductivity of silicon from room temperature up to the melting point was studied.[1] The effect of random variation of impurity concentration on Fermi level in *n*-type silicon was theoretically investigated.[4] The characteristics and fabrication of high voltage silicon diodes were reported.[13] Results of an experimental study of instability in thermally grown SiO_2 films were presented.[18]

High electric field measurements at 50 and 80°C on amorphous Semiconducting $(As_2S_3)_{1-x}(PbS)_x$ were reported.[2] Electrical properties of polycrystaline germanium-metal films were studied at different temperatures; the results were explained in terms of formation of solid solution/segregated ordered phases.[21] Transport in silver doped $As_{10}Ge_{15}Te_{75}$

glassy alloy was also investigated.[22] Resistivity and current-voltage characteristics of CdSe films sandwiched hetoran two Al electrodes were reported.[26] Vacuum deposited HgTe films formed at 120°C were studied for resistivity, activation energy, Hall constant, mobility and thermoelectric power between 78 and 420 K.[29] Structural aspects, infrared spectra, electrical transport and magnetic properties of some Ln_2MoO_5 oxides were reported.[33]

Transient capacitance plots of metal-oxide-semiconductor capacitors were numerically computed and surface state distribution was determined therefrom.[3] Potential feedback in field-effect devices was investigated.[6] A new technique was described for analysis of linearly graded and Gaussian graded *p-n* junctions.[9] The conventional method to determine the mechanism of current transport in Schottky barrier diodes was shown to fail in a large-area diode.[14] DC field and carrier current density profiles of linearly graded double drift avalanche diodes were studied in detail.[15] A second order nonlinear differential equation was numerically solved to compute profiles of electric field and current density in *p-i-n* avalanche diodes.[30] Nature and degree of variation in current gain caused by perturbations in processing and material parameters in normal and I L (inverse) transistor, formed by double-diffusion process, were studied.[16] A coplanar device incorporating an evaporated CdSe film and anodically grown aluminium oxide layer was reported.[17] A theoretical study was made on the behaviour of metal-*p*-*n*-Si Schottky barrier solar cell.[19] A computer-aided analysis was made to study the effect of a linear potential variation on the gate of an FET. A simple two-post model was constructed to predict the frequency and transient characteristics of MOS transistors.[25] Modelling of double diffused transistors was reported.[27]

Thermoelectric power of *n*-GaAs was studied in detail by an iterative solution of the Boltzmann equation including relevant details of band structure and scattering mechanisms.[7] Hall coefficient, DC conductivity and thermopower in heavily compensated zinc selenide crystals were studied.[5] Growth of acoustic waves in a piezoelectric nonparabolic nondegenerate semiconductor was analytically investigated.[8] Microwave

measurements of complex permittivity and conductivity of silicon were made.[10] The mobility measured in an annealed crystal of CdS was found to be lower than that predicted by the Brooks-Herring formula.[11] Hole transport properties in gallium antimonide with doping concentrations of 8×10^{17} and 3×10^{18} cm^{-3} were studied.[12] The effect of electron spin was found to enhance the plasma frequency of a narrow-gap semiconductor under a quantizing magnetic field.[20] The regional approximation method was used to evaluation approximate solutions for the current-voltage characteristics of hot carriers in single-injection solid state devices with exponential trap distribution.[23] A Monte Carlo calculation of low-field electron mobility in InSb was reported.[28] Technology was developed for the growth of high purity GaAs epitaxial layers and for fabrication of X-band Gunn diodes.[31] Millimeter and far infrared conductivity of *p*-Si was studied.[32]

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A unified approach was used for the calculation of current gain of planar transistors, considering the double Gaussian model of the transistor.[1] Vertical N-P-N and lateral P-N-P transistor structures of an integrated circuit were studied for current gain using an electrolytic tank analogue.[2] Dependence of the C-V index on junction parameters was studied assuming a practical diffusion profile, viz., a complementary error function or a Gaussian or a type of distribution in the retrograded side of a hyperabrupt junction.[3] High frequency noise properties of a double avalenche region (DAR) IMPATT diode were investigated.[8] The effect of dopant distribution and built-in electric field on the transit time of a transistor was found to be detrimental to its high frequency performance.[9] Annealing effect on DC current gain of silicon planar transistors was

studied; by annealing the devices in hydrogen ambient, the current gain was observed to increase remarkably.[13] Schottky diodes were fabricated by electro-chemical deposition of copper on *n*-epitaxial silicon.[12] Analytical solutions were reported for the breakdown voltages of punched through diodes having curved junction barriers at the edges.[17] Injection phase delay in high-power Baritt oscillators was studied.[18] Fabrication of metal-semiconductor Schottky barrier junctions was described.[21] Fabrication of silicon Schottky diodes by electro-deposition technique and their electrical characteristics were also reported.[22]

DC conductivity measurements from 4 to 300 K and Hall mobility and magnetoresistance measurements from 77 to 300 K were made on degenerate *n*-GaAs; impurity band conduction was found to be significant even at 140 K.[3] Electrical properties of thin films of InTe were reported.[5] The dependence of room temperature negative bias instability in SiO_2 films grown in O_2-trichloroethylene on the chlorine concentration was studied; possible mechanisms for this dependence were suggested.[6] Photoresponse of Al-amorphous Ge-nSi systems was studied.[11]

Frequency and temperature dependences of the real and the imaginary parts of the high frequency electron mobility in $Ga_{0.47}$ $In_{0.53}$ As were theoretically studied by an iterative solution of the Boltzmann equation, the results were shown to be sensitive to the value of the alloy scattering potential.[10] The effect of magnetic quantization on the surface capacitance of MOS field-effect devices was theoretically studied.[14] Spiky oscillations in the capacitance value with changing magnetic field in the case of MOS structures of small-gap semiconductors were investigated.[15]

It was observed that the effect of a negative gate voltage in *p*-type InSb MIS structures was to decrease the Hall mobility and grain boundary barrier potential.[16] The origin of the high electronic current density in anodic oxidation of silicon was investigated.[19]

Harmonic generation due to the hot electron nonlinearity in Si-inversion layers in the presence of a large high frequency signal was studied on a displaced Maxwellian model.[7] The efficiency of second harmonic generation due to hot electrons

in II-VI compound semiconductors was also obtained.[20] A Monte Carlo study of the hot electron noise properties of *n*-InSb was reported.[24] Investigations on the generations of excess minority carries in MOS devices due to gamma irradiation were carried out.[23]

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COMMISSION F

WAVE PHENOMENA IN NON-IONIZED MEDIA

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INTRODUCTION

THE work carried out in India in areas relevant to this Commission, as evidenced from publications in the last three years, is essentially confined to tropospheric propagation. This report does not include the research efforts of some operational organisations such as the Defence Laboratories, P & T Laboratories and Railways because the output is either not published or published as restricted Lab reports.

In the late 60s and early 70s, the tropospheric propagation work in India was directed towards determining if the propagation data and prediction procedures applicable to temperate zones could be applied to India. It was soon realised that the Indian sub-continent with its long coastal line and extremely dry desert areas encompasses a wide variety of climatic zones. Detailed data collection and analysis were realised to be essential to parameterise LOS and scatter communication systems in the various zones. The research efforts in the country in the last 3 years can be broadly categorised into the following areas :—

1. Characterisation of tropospheric medium.
2. Path loss prediction and link establishment procedures.
3. LOS propagation studies.
4. Troposcatter propagation studies.
5. Rain and water vapour attenuation studies.
6. Anomalous propagation.

1. Characterisation of the Tropospheric Medium

The characterisation of the radio medium was essentially based upon the countrywide radiosonde measurements organised by the India Meteorological Department as part of the global net work. During the last 3 years, these stations have increased from 16 to 25. In addition to these routine measurements, successful attempts were made in the recent past to obtain data using the kytoons upto a few hundred meters by the Tata Institute of Fundamental Research (TIFR) and the Radar Communication Project Office (RCPG). Efforts are being made to conduct countrywide measurements using kytoons upto an altitude of 1km. One of the techniques used to characterise the boundary layer in terms of microwave propagation characteristics is the acoustic radar. The group at the National Physical Laboratory, New Delhi has a SODAR with a capability of probing thermal structures upto 600 meters.[1] The SODAR data alongwith field strength data from a LOS link has been studied to characterise the bondary layer in terms of surface based inversions, transitions frnm stable to unstable conditions and elevated layers. Acoustic Radars with a proven capability of at least 1km, are operating at Punjabi University, Patiala[2&3] and at Vikram Sarabhai Space Centre, Trivandrum, and a number of propagation studies are in progress. Radio-refractivity changes associated with the sea and land breezes along the Arabian sea and Bay of Bengal coasts and their influence on microwave propagation were studied to characterise the coastal radio environment. It was found that refractivity conditions are influenced not only by the prevailing pressure gradients, but also by the temperature variations of the sea surface with latitudes.[4] Based on radiosonde observations over the Arabian sea during ISMEX – 1973 under Indo-Soviet collaboration, models of radio refractivity index were derived along latitudes of 11° N and 16° N extending upto the Arabian Coast.[5] The India Meteorological Department has used the data from Monex 79 experiment to derive Radio Refractivity morphology over Bay of Bengal and over S. Arabian Sea.[6,7&8]

2. Path Loss Prediction and Link Establishment Procedures

A troposcatter link for experimental studies at 4.6 GHz was established during the year 1980 between IIT, Delhi and CEERI, Pilani. Field strength trials were conducted along the route with mobile field intensity meter and the variations were studied as the link transcends from line-of-sight to scatter mode. The results were compared with Met parameters and it was found that the link starts behaving in tropo-mode beyond 80km. Comparisons were made with the existing prediction techniques such as NBS 101 (modified) and the NPL technique.[9] A comprehensive survey of link establishment procedures was prepared including terrain profiles, antenna systems and the dominant propagation modes for typical Indian zones and suggestions were given for design specifications.[10]

3. LOS Propagation Studies

The group at the National Physical Laboratory at New Delhi has been monitoring a number of LOS links in the Northern, Eastern and Southern sectors. A number of reports were brought out discussing the field strength variations and their relationship with the observed meteorological conditions. LOS propagation characteristics observed at 6 GHz between Dum Dum and Andul situated on the Indian East Coast alongwith a link at 6.7 GHz have shown that the scintillation frequency increases with the wind component and that the wave length dependence in turbulence conditions varied between -1.3 and -0.08 whereas for layer conditions it varied from 0.4 to 2.3.[11] Atmospheric turbulence parameters were deduced from radiosonde measurements and from spectral analysis of LOS fading independently. It was found that the spectral slope is a characteristic representation of atmospheric structures present in the medium and that the spectral intensity enables to determine Tatarski's structure parameters C_n.[12] The tornado that struck North Delhi on 17th March 1978 severely affected the microwave line-of-sight between Delhi and Sonepat. A study of the signal behaviour during the event is reported, the special interest being that the tornado represents a refractivity variation brought out by large pressure variations.[13]

The signal strength recordings made on a 24-hour basis since 1976 on a LOS link at 7640 MHz over a path length of 42km and on yet another link at a frequency of 6580 MHz were analysed to study the dawn dusk transitions. The studies show that the morning transition is characterised by an enhancement in the signal level for a short period of time and is associated with the rise of the ground-based inversions due to the solar heating of the ground. The absence of morning transition is maximum during monsoon period. A long stretch in the occurrence of the morning transition seems to indicate a high degree of variability in the atmospheric conditions over northern plains compared to east coast.[14&15]

4. Troposcatter Propagation Studies

The aperture-to-medium coupling loss in troposcatter systems was studied with a view of optimising antenna sizes. Assuming isotropic homogeneous turbulence and a common volume between transmitting and receiving antenna beams with a turbulence charecterised by the parameter C_n^2, it will not be of any advantage to increase the size of the receiving antenna beyond a particular dimension to take advantage of scatter power. An expression has been developed for some Indian zones using a realistic model of the atmosphere for the estimates of the antenna gain degradation.[16] The Radar Communication Project Office (RCPO) has analysed the data obtained from several troposcatter links on 2 GHz to derive the aperture-to-medium coupling loss experimentally. The antennas used for comparison were of 60' and 85' diameter.[17]

Analysis of troposcatter field intensity data conducted by NPL, New Delhi shows that the field strength reaches maximum around midnight when the reflection from the Glints and Layers are stronger; reaches minimum around noon when the field strength is entirely due to turbulence scatter. The Indian Institute of Technology, Kanpur conducted propagation studies using a tropo-link between Kanpur and Nainital and using radiosonde data obtained from Lucknow. They observed the correlation to be better with the initial refractivity gradient than with surface refractivity. They also conducted airborne microwave refractometer experiments in the common volume of the link over Saharanpur.[18]

5. Rain and Water Vapour Attenuation Studies

A microwave radiometer to conduct rain attenuation measurements at 10, 11, and 18 GHz was fabricated at NPL, New Delhi. The long-term cumulative distribution of rain attenuation at these frequencies has been obtained. For about 0.01 per cent of the time the attenuation during the monsoon period was as high as 14.4 db.[19 & 20]

Water vapour attenuation studies at 22.235 GHz by using microwave radiometer were also conducted by NPL New Delhi.[21 & 22]

Water vapour content over the northern regions of India was derived using radiosonde measurements and the values were compared with radiometric observations over New Delhi[23] using line-of-sight links operating at 7 GHz in northern India. Rain attenuation studies conducted simultaneously with rain rate measurements using special rain gauges of 30 sec. integration time.

6. Anomalous Propagation

Simultaneous measurements of ground-clutter extent using a radar at low elevation angles and Kytoon measurements of Radio Refractivity Index profiles were conducted over the Indian coastal regions to study super-refraction and ducting. The morphology over a 3 month period shows both ground based and elevated inversions and the correlation was maximum when the gradient between surface and 300 meters was used.[24]

Unexpectedly large occurrences of anomalous T.V. receptions in channel 2 and channel 3 of Band I were observed at Delhi from a study conducted by the National Physical Laboratory. In addition to tropospheric ducting and sporadic *E*, ionospheric heating was also suspected to cause such long range reception.[25] Anomalous T.V. propagation over transhorizon paths was studied by the All India Radio in Bands I and III. It was observed that the phenomenon is more pronounced during winter nights. No correlation was apparent with surface refractivity values (C.C.I.R. input to National Working group V during 1980).

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COMMISSION G

IONOSPHERIC RADIO AND PROPAGATION

Prepared by

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1. INTRODUCTION

RADIO waves have been extensively used by many Indian groups to prove the upper atmosphere and thus obtain information about the D, E and F regions and the magnetosphere. The techniques used include Vertical Ionospheric Sounders, Spaced Receivers and Partial Reflection, Phase path, Vertical and oblique radio propagation, VHF radar, and Faraday rotation and scintillation of HF radio signals from beacons on satellites. With regular rocket-launchings carried out regularly from the equatorial location Thumba (TERLS), and occasionally from the low-latitude stations Sriharikottah (SHAR) and Balasore, the ionosphere is probed '*in situ*' and a wealth of information has accrued. With India having successfully put a satellite into earth-orbit in July 1980, access of Indian scientists to '*in situ*' data on the Upper atmosphere has been greatly increased.

All these radio techniques were utilised by Indian scientists to understand the solar and atmospheric changes during the recent total solar eclipse of 16 February 1980, and a rich collection of results is undergoing interpretation.

Recently, the idea of using high-power VHF radar for studying atmospheric parameters at mesospheric heights, as well as at troposphere-stratosphere heights has been activated. There have also been suggestions by Indian scientists for setting up an Incoherent Scatter Radar in the Indian equatorial region, and design calculations for a feasible set-up have already been performed.

Summarised here is a report of the results obtained by various Indian groups using techniques to probe the Upper atmosphere. Given first is a list of Indian Research Institutes, and Universities and Colleges actively engaged in radio studies of Space, with the abbreviations of their names, given in alphabetical order. The abbreviations are used in the work-report which follows.

2. List of Organisations in India involved in Radio Studies of the Upper Atmosphere

(*a*) *Research Institutes*

1. IIA—Indian Institute of Astrophysics, Kodaikanal.
2. IIG—Indian Institute of Geomagnetism, Bombay.
3. ISRO—Indian Space Research Organisation.
   (a) TERLS—Thumba Equatorial Rocket Launching Station.
   (b) SAC—Space Application Center, Ahmedabad.
4. NPL—National Physical Laboratory, New Delhi.
   (a) Radio Science Division.
   (b) Time and Frequency Section.
5. PRL—Physical Research Laboratory, Ahmedabad.
6. VSSC—Vikram Sarabhai Space Centre, Trivandrum.

(*b*) *Universities and Colleges*

1. AIR—All India Radio Research Department, New Delhi.
2. APSU—APS University, Vikram Space Physics Centre, Rewa.
3. AMU—Aligarh Muslim University, Physics Department, Aligarh.
4. AU—Andhra University, Physics Department, Waltair.
5. BHU—Banaras Hindu University, Varanasi.
   (a) Applied Physics Dept.
   (b) Physics Department.
6. BEC—Bengal Engineering College, Department. of Electronic and Telecommunication Engineering, Howrah.
7. CARPE—University College of Technology, Centre of Advanced Study in Radio Physics and Electronics, Calcutta.

8. CEA—College of Engineering, Department of Applied Physics, Amravati.
9. DU—Delhi University, Ionospheric Research Centre, Physics Department, Delhi.
10. IRPE—Institute of Radio Physics and Electronics, Calcutta University, Calcutta.
11. Ga U—Gauhati University, Physics Department, Gauhati.
12. GU—Gujarat University, Physics Department, Ahmedabad.
13. ITUE—ITU College of Engineering, Physics Department, Kakinada.
14. KU—Kurukshetra University, Physics Department, Kurukshetra.
15. KJSCS—KJ Somia College of Science, Physics Department, Bombay.
16. PU—Punjabi University, Patiala.
17. RBSC—RBS College, Physics Department, Agra.
18. REC—Regional Engineering College, Physics Department, Srinagar.
19. SU—Saurashtra University, Physics Department, Rajkot.
20. UP—University of Pune, Physics Department, Pune.
21. UK—University of Kerala, Physics Department, Trivandrum.
22. UJ—Jodhpur University, Physics Department, Jodhpur.
23. Ut U—Utkal University, Physics Department, Bhubaneswar.
24. UU—University of Udaipur, Physics Department, Udaipur

3. Summary of Studies and Results by Various Techniques

3.1. Ionospheric Sounding

Ionospheric studies at Kodaikanal (+3.5° dip) showed sudden pre-sunrise appearance of range-type Spread F and this was linked with anomalous night-time reversal of E-region East-West electric fields (IIA). The Physics Department at Gauhati University (26°.2 N, 91°.8 E) also carries out studies of the ionosphere. From these observations, the occurrence of

E_s has been related to F_{min}. F region data recorded at Gauhati was used to understand storm-time changes in this parameter, and thereby infer storm-time dynamics (Ga U) Data from the topside ionosphere recorded by ISIS satellite was received at Ahmedabad (+34° dip) and showed that during counter-electrojet events, the movement of anomaly crests towards the equator is a clear indication of reversal of eastward electric field at low latitudes (PRL).

3.2. Phase-Path Technique

Phase-path technique was used at Waltair (17°.7N, 83°.3E) to study vertical movement of the ionosphere during the presence and absence of Spread F. T.I.D. in the F region using 5.6 MHz probing frequency was studied to understand the anisotropy in gravity waves. Short-period fluctuations in F-region echoes were found to accompany thunderstorm activity. Dispersion was found in F region T.I.Ds and was interpreted as dispersion of the causative gravity waves (AU).

3.3 Spaced Receiver Drift and Partial Reflection Technique

Partial reflection technique was used at Ahmedabad (23°N, 72° 6E) to examine the effect of magnetic activity on D region electron density—no correlation was seen. The day-to-day variability in ionospheric drift obtained by spaced receiver at Tiruchi (+4°.8 dip) was related to electrojet strength at equatorial locations. The relationship was found to be linear in the noon hours but departed from this in the morning hours (PRL). Ionospheric drifts measured on 2.5 MHz and 3.0 MHz at Udaipur (24°.7N, 73°.7E) were used to calculate various drift and anisotropy parameters for the F region. An attempt was also made to correlate Interplanetary Magnetic Field with observed drift speeds ; this analysis suggested both East and West drift speeds to decrease with increasing Northward intensity of Bz. The effect of size and orientation of receiving triangle on night time F region drift was examined (UU).

3.4. Meteor Wind Radar

Meteor Wind Radar equipment was fabricated by Andhra University, Waltair (17°.7N, 83°.3E), and was installed at their Nagarapalam field station. Observation with this set-up yielded considerable interesting information on meteors.

Observations on 36 MHz were used to evaluate echo duration, and diffusion coefficients of under-dense meteor trials. The diurnal variation of diffusion coefficient showed a maximum in the morning hours, and a minimum in the evening hours. Various periodicities were observed in meteor count-rate, and attempts were made to link these with relevant wave phenomena. Meteor wind radar was also used to examine the neutral winds in the region 80–110 km; observations showed that the prevailing zonal wind speed varies from 6 to 25 meter per second, and the meridional wind from 0.2 to 18 meters per second. The diurnal component is the most dominant amongst all the tidal modes (AU). VHF forward scatter link between Dehra Dun and Waltair was also used to study meteor showers (AU, and Defence Electronics and Applications Laboratory, Dehra Dun).

3.5. Whistler Studies

These have been mainly measured at Varanasi ($+15°.6\phi$) and at Nainital ($+19°\phi$). From the observations, magnetospheric parameters such as electric fields, electron density, magnetic tube content and electron temperature were estimated (BHU). The occurrence of sweepers on 29 5 MHz and higher harmonics, and their direction of arrival were studied (CLRPL).

3.6. VHF Radar Studies

VHF radar observations at Thumba ($-1°\phi$) show that internal gravity waves produce observable fluctuations in electric fields and currents within the equatorial electrojet. Maximum westward electron drift speeds were observed at 104km altitude; while currents above 100km are eastward, currents below 100km appeared to be westward. Changes in currents and electric fields in the equatorial electrojet were quantitatively determined from VHF radar observations at Thumba ($-1°\phi$) and thus the magnetospheric current contribution during geomagnetic storms was separated out. In efforts to link ionospheric processes at Auroral latitudes with those at equatorial latitudes, it was seen that small-amplitude, bay-type disturbances at auroral latitudes have clear counterparts in the equatorial electrojet as observed by radar. In contrast, counter electrojet events do not seem to have any counterparts in

auroral records. Examination of lunar effects showed that while the ground-based magnetometer did not record any significant change in H at full or new moon, VHF backscatter radar observation of the electrojet did show a significant reduction at such times. This suggested a height structure in the electrojet currents (VSSC).

Radar echo amplitude at Thumba ($-1°\phi$) was related to the drift velocity of the plasma irregularities in the E region ; while there is generally a linear relationship between these parameters, on certain occasions this linearity breaks down. VHF observations at Thumba ($-1°\psi$) show that the radar echo vanishes at the onset of a counter electrojet. An electrojet index

$$\triangle H = \triangle H_{\text{TRV}} - r \triangle H_{\text{ALB}}$$

with r less than 1 was emperically derived as a better index. The radar echo also showed short-period fluctuations in amplitude which suggested localised currents in the region around the electrojet peak (PRL).

3.7. Rocket Studies

Rockets launched at the equatorial region Thumba ($-1°\phi$) during Spread F conditions saw a hole in the electron density profile at 150 km. Another rocket-launch showed total absence of plasma irregularities in the equatorial electrojet region during weak and strong counter-electrojet events. Centaur rockets from Thumba ($-1°\phi$) were used to observe sharp ionisation layers at sunrise ; the predominantly iron content of these layers suggested their origin to be in micro-meteors. E_s irregularities examined by rocket-borne probes suggest that the E region electric field is downwards between 95 to 110 km, and upwards between 110 km to 130 km. The passage of a rocket itself disturbs ionospheric plasma-parameters in a manner dependent on the ambient plasma parameters, and on the dimensions of the rocket. The height-distribution of ozone, and atmospheric scattering in the middle UV wave length band were determined at Thumba by rocket-borne photometers (PRL).

The temperature structure of the meso use over the equatorial station Thumba (8°N, 76°E) has been assessed from M-100 rocket data. Mesospheric warmings were studied and

showed that peak warming temperature of about 20°C is in December-January, and is accompanied by a drop of about 4°C in stratosphere temperature (TERLS, ISRO).

Electron density and temperature were measured in the 90 to 133 km region during a partial counter electrojet, and clearly differed from the pattern during normal days (VSSC). Positive ion profiles in the mesosphere (60-100 km) and in the stratosphere (23–40 km) were obtained over the magnetic equator ; at mesospheric height the values obtained at this low latitude agreed with those at mid latitudes, but there was some difference at stratospheric heights (NPL). Rocket observations of the D-region at Thumba were examined to derive electron production and loss parameters (Ut U).

3.8. Radio Propagation Studies

Periodicities in ionospheric absorption at 2.4 MHz and 5.6 MHz at Waltair (17°.7N, 83°.3E) were examined for effects of magnetic activity. Geomagnetic control on obsorption seems to be present only above a certain level of magnetic activity. The attenuation of VLF as a function of azimuth was studied by recording atmospherics. 10 MHz ATA signal from Delhi (28°.5N, 77°:3E) was recorded at Waltair (17°.7N, 83°.3E) ; wave structure of the Doppler-shifted signal showed periodicities of 2-4 minutes probably due to F-region gravity waves. Periodicities in ionospheric absorption at 2.4 MHz and 5.6 MHz at Waltair (17°.7N, 83°.3E) were examined to obtain an idea of the atmospheric changes causing absorption. From AI absorption data at 2.0, 2.2 and 2.6 MHz at low latitudes, D and E region electron density profiles were obtained. Fading of 2.4 MHz vertically-reflected signals were examined with a view to understanding the source responsible for periodicities of a few minutes. Multi-frequency ionospheric absorption was used to determine the zenith angle dependence of the frequency variation index '*m*' (AU).

The phase amplitude of 16 kHz signal from Rugby and 10.14 MHz Omega signals were recorded at Delhi (28°.5N, 77°.3E) and examined for day-to-day variability, seasonal changes, and solar and geomagnetic disturbance effects. The 22.3 kHz signal from NWC (Australia) recorded at Delhi showed the unusual feature of daytime signal amplitude being larger

than at night-time. The amplitude variation of the 164 kHz Tashkent signal observed at Delhi during pre-sunrise hours was understood in terms of the penetration of UV (2600–3200Å) through the ozone layer. Long distance TV signals were recorded at Delhi and long-term behaviour was interpreted in terms of propagation *via* E_s and normal F in the noon hours, and at night *via* an ionosphere artifically modified by man-made signals. VLF phase and amplitude measurements of 22.3 kHz from NWC (Australia), recorded at Delhi (28°.5N, 77°.3E) were studied for the solar eclipse effect of 23rd Octobey 1976. While the amplitude did not show much change, the reflection height registered an increase of 5 km during totality. Simultaneous sounding from Kytoon and radar were used to determine ground-clutter dimensions. Atmospheric modelling was used to relate antenna gain to antenna configuration, power pattern, and climatology of the environment. The effect of rain on 7 GHz propagation was found to attenuate the signal by 4–8 dB depending on the intensity of the shower. Rain-attenuation on the 11 GHz signal was also studied. The microwave link (7 GHz) between Delhi and Sonepat showed sharp responses to a powerful tornado that crossed its path on 17th March 1978 ; salient features were a rise of 5 dB in signal strength one hour before the event; and a drop of 15 dB during the event. The effects of meteorological conditions corresponding to Clear, Cloudy and Rainy on 18 GHz and 22.2 GHz were studied at Delhi (NPL).

The 164 kHz Tashkent transmission and the 182 kHz Alma Ata signal recorded at Delhi were used to evaluate parameters of the lower ionosphere such as reflection height, recombination coefficient, flare-time absorption, and diurnal and seasonal solar cycle variations. The fading characteristics of LF between 150 and 372 kHz over path lengths of 100 to 1200 km were examined. Sudden change in longwave (SCL) observed during solar flares, on 164 kHz and 182 kHz transmissions, were of three distinct types ; each type seemed to be associated with a different X-ray wavelength band of solar emission. The use of SCL in short-term forecasting of magnetic storms was shown. The propagation coupling loss on MF was estimated from sky-wave field strength measurements and compared with values obtained from the standard CCIR formula (AIR).

Multi-frequency ionospheric absorption measurements at Udaipur (24°.5N, 73°.7E) were used to calculate D, E and F region absorptions, the zenith angle-dependence index n, and the frequency-dependence index m. Anomalous night time absorption oblique incidence was attributed to E_s reflection. Vertical and oblique reflection of 3.2 MHz was studied, and observed absorption was compared with calculated absorption. Solar cycle changes in the diurnal variation of D region electron density were obtained from absorption studies of 2.3 and 2.5 MHz (UU).

Amplitude and phase changes in 2.2 MHz signal determined by the Al method were used to estimate vertical drift velocities in the E region at Calcutta. A precursor due to H-rays with $\gamma = 8$–20A seems to precede the main solar flare effect observed on LF and HF signals monitored in Calcutta. Seasonal changes and anomalies in absorption of VLF, LF, MF, HF monitored at Calcutta were examined. Phase fluctuations in these recordings were related to variations in reflection height (CARPE). Step-like structures were noticed during sunrise on VLF atmospherics at 10.20 kHz and 30 kHz; these were interpreted in terms of atmospheric sources (CU and IRPE).

Field-strength measurements on 7.6 GHz (Delhi-Sonepat) and 6.8 GHz (Dum Dum-Andul) showed sharp enhancements in the morning which seemed to be governed by season; these were linked with the temperature-gradient, and rate of rise of temperature-inversion layers. Evening periods are characterised by the appearance of small-amplitude scintillations with no appreciable change in signal strength (NPL and IRPE).

Al absorption method at Ahmedabad on three different frequencies was used to relate seasonal and solar cycle variations to change in atmospheric and ionospheric parameters (GU). C.W. transmission of 4.8 MHz was affected by Spread F and by increased height of F region irregularities; it was observed that the fading frequency increases at such times (ITUE). The effect of thunder storm on LF and VLF was noticed at Pune (KJSCS). Multipeaked structure in the amplitude of vertically-reflected radio signals at 2.4 MHz and 5.6 MHz was explained as corrugated structure in the ionosphere (IIA and AU).

3.9 Satellite Beacon Studies

3.9.1. Faraday Rotation and TEC : An extensive study of Faraday rotation and group-delay, of signals from the ATS-6 satellite was carried out by PRL at a number of locations all over India during 1975–76, and analysis of this data was continued. From these measurements, the electron content of tne plasmasphere was obtained. The effect of geomagnetic storm and solar wind speeds on plasmaspheric content was examined. The observations were used to construct TEC contours over the Indian sub-continent. TEC obtained from 140 MHz signal was analysed to obtain lunar tides. Lunar perturbations were found to be of the order of $(1–4)+10^{16}$el/m^2. The phase of the lunar semi-diurnal oscillation at anomaly trough station, Ooty (+2.2° dip) lagged behind that at anomaly crust by about 2 hours (PKL).

TEC measurements from the ATS 6 satellite were also carried out at Delhi (28.6°N, 77.2°E). Night-time TEC showed steady levels; occasionally midnight increases were observed during winter months and these were used to estimate night-time influx of ionisation. Faraday rotation records were used to study the periodicities, speeds, and amplitudes of T.I.Ds in the F-region; the energy of the associated gravity waves was estimated. The 40 MHz and 41 MHz signals monitored from the INTASAT satellite showed signal enhancement of tropospheric origin, which depended on elevation angle of the signal, and on season. The $n\pi$ ambiguity in Faraday rotation introduces large errors in night-time estimates of TEC—a method was evolved to resolve this this ambiguity in n (NPL). Frensel-type fading on ATS-6 beacon recordings received at a low-latitude station are explained as due to patches of ion isation ranging from a fraction of a kilometer to some tens of kilometers, located in the E and F regions. The Farady rotatiion of 140 MHz signals during the annular eclipse of 29 April 1976 showed quasi-periodic variations in TEC. Day-to-day variability in TEC from Faraday rotation of signals from the ATS-6 satellite and the peak F2 electron density NmF 2 from relevant ionosondes were studied; long-term variations in both parameters seem to be associated with 10.7 cm solar flux (NPL and KU).

T.I.Ds over the magnetic equator were studied using Faraday rotation and modulation of the 40 MHz transmission from the ATS-6 satellite. Power spectrum analysis showed various periodicities which were interpreted in terms of internal gravity waves. It was also seen that at the equator the noon-time bite-out which is so prominent in N_mF2 is generally absent in TEC (VSSC).

Model calculations of gravity wave-induced perturbations in TEC were compared with observations from ATS-6 (DV). The 360 MHz signal from the ATS-6 satellite was used to understand the relationship between variations in electron content and electron density (SU). Faraday rotation on 136 MHz from ETS-2 satellite was recorded at Waltair; this was used to understand the diurnal, seasonal, and storm-time response in TEC and the occurrence of T.I.Ds. Storm time deviations in TEC obtained at Waltair from the ETS-2 satellite were as large as 50%, and seemed to depend on the local time of storm mainphase (AU). The variation of slap thickness was examined using ATS-6 data recorded at Patiala and Udaipur and the relevant F region data (PU). The effect of solar and geomagnetic activity on TEC was studied at Udaipur (24°. 5N, 73°, 7E) from ATS-6 records (UU).

3.9.2. Scintillation Studies: Amplitude scintillations on MHz, 140 MHz, and 360 MHz signals from the ATS-6 satellite, are understood in terms of change in scale sizes and thickness of ionospheric irregularities. Radio signals from ETS-2 satellite were received on Spaced receivers at Tirucni (11°N, 79°E); from the scintillations observed the velocity of the scattering irregularities was obtained. Scintillation index variations were compared with the predicted variations from the Fremow-Rino model. Radio signals on the 136 MHz (VHF) and 4 GHz (S band) from the Symphonic satellite were received at low-latitude Car Nicobar (92.7°E, 9.3°N). The scintillation observed suggested that the 4 GHz transmission is affected by tropospheric irregularities in addition to irregularities in ionosphere (PRC).

136 MHz signal from ETS-2 geostationary satellite showed transient scintillations. By comparing scintillation on 136 MHz from ETS-2 and GEOS satellites, the movement of

irregularities was traced and the vertical extent of irregularities was estimated (IRPE).

Amplitude scintillations on 136 MHz from ETS-2 satellite were recorded at Kurukshetra; these were used to study the morphology of scintillation and the electron content of TID's. The effect of F-region vertical movemet on scintillation of 40 signals was analysed. It was shown that the Fresnel type diffraction patterns on the 140 MHz signal from ATS-6 were caused by Es irregularities, not sprepd F (KU and NPL). Scintillations on the 136 MHz signal from the FTS-2 satellite were recorded at Waltair, and were examined for nocturnal and seasonal variations (AU). Night-time scintillations with high fading rate over the magnetic equator were modelled, using the observed scintillations from the ATS-6 as a reference (VSSC).

4. Analysis, Interpretation and Modelling of Ionosphere Using Global Data

Ne profiles obtained from IRI (International Reference Ionosphere) were compared with ionosonde observations from Delhi, Ahmedabad and Thumba; considerable mis-match was seen. Solar activity changes in TEC and parameters associated with T_e such as electron cooling rate, ion composition, and field aligned heat flux were examined. Ion drag and electric fields were inferred from ion drift and incoherent backscatter data. Photo-electron fiux and thermal electron heating rates were modelled for magnetic field lines with $L=1.16$, $L=1.14$, $L=1.12$ and $L=1.10$. F-region production rates and vertical drift velocities were estimated from electron density profiles. Vertical profiles of ion composition, T_e, and T_i were computed for various phases of solar activity. Improved mathematical techniques yielded more accurate predictions of F-region critical frequencies at low-latitude locations. Dawn and dusk gradients in f_o F2 were studied, from topside sounder and incoherent scatter data, and were interpreted as rapid changes in plasma temperature and diffusion patterns (NPL).

Dynamics of the low-latitude F region and the parameters n(0) (atomic oxygen concentration), and β (recombination coefficient) were evaluated from f_oF2 and h_mF2. The slope of

the relationship between these F-region peak perameters was seen to vary in a systematic way with local time and latitude. The slope was used to infer the chemical and transport processes at work in the quiet F region. The change in slope during geomagnetic disturbance was explained in terms of storm time dynamics. Using interpolated *N-h* data, from the topside ionosphere, plasma scale heights and ion transition altitudes were estimated and their latitudinal variations derived (IIG).

Partial reflection observations were used to estimate eddy diffusion coefficients in the mesosphere ; increase in horizontal wind speed was found to decrease the eddy diffusion coefficient. Spread F at equatorial stations Kodaikanal and Huancayo was examined for magnetic activity effects; the two locations showed clear seasonal and local time differences. A mechanism for transmission of E-region electric fields to the F region was suggested. The F region continuity equation was solved using winds and electric fields appropriate to solar maximum and minimum conditions (PRL). The role of NO in the formation of a minimum value in the electron density profile at 70 km was demonstrated from model calculations (PRL and Stockholm University).

F_{min} subjected to spectral analysis, showed planetary scale periodicities of 12.6 days at low latitudes and 6 days at mid latitudes. The noon bite out in the equatorial F region was examined in relation to IMF sector structure; a solar cycle-dependent relationship was found. Es occurrence at mid latitude stations was examined in relation to geomagnetic storm activity; both lags and leads with respect to magnetic activity were obtained. The diurnal development of the equatorial F region anomaly in the topside was studied for different seasons from Alouette 1 data. The effect of changing solar activity on night time f_0F2 at low and mid latitudes was examined, and the coefficients '*a*' and '*b*' in the relationship

$$f_0F2 = a\,(1 + bF_{10\cdot7})$$

were evaluated (AU).

Rocket-based data on N_e and N_i were used to understand the winter anomaly in the D region. Anomalous days were characterised by enhanced NO and mesospheric temperatures with wave-like patterns. D region ion composition and NO

enhancement during winter anomaly days was analysed from published rocket data (Ut U).

The degradation introduced into satelliite to ground communication by ionospheric dispersion and scintillation was modelled (UK and VSSC). TEC and f_0F2 were examined for sudden commencement storms between 1968 to 1972; the time-dependence and intensity-dependence of the ionospheric parameters on geomagnetic activity was obtained (UK and SU). Latitudinal and solar cycle variations of night Es were examined (UU) Emperical relationships were established between solar activity and ionospheric absorption at a low latitude location and the possibility of using this for radio predictions was shown (GU). The nature and origin of equatorial blanketing type of Es was assessed from observations by various techniques (IRPE). Ionospheric models were used to model out low-latitude VLF propogation. The effect of equatorial anomaly on waistler propagation at low latitudes was examined (RBSC). A number of groups investigated solar flare occurrence and emissions of the disturbed sun in the X-ray, gamma ray and microwaves bands (AMU, CEA, BHU, IIA, CARPE, PRL).

COMMISSION H

WAVES IN PLASMAS

Prepared by

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BASIC PROCESSES OF LINEAR WAVE PROPAGATION

Dispersion Characteristics

EXPERIMENTAL results obtained on multiple life times for nonadiabatic leakage of charged particles in a magnetic mirror trap have been investigated confirming the model proposed earlier (Bora *et al.*, 1979*a*, *b*, 1980).

Experiments on the interaction between moving magnetised plasma and a stationary neutral gas show that Alfven critical velocity is the only relevant velocity in the interaction (Mattoo and Venkatramani, 1980). These results have important relevance to the formation and evolution of the solar system.

The Chew-Goldberger and Low equations have been applied to study the effect of resistivity on the stability of plasma jet (Srivastava, 1978) and to investigate the parallel velocity shear instability in an inhomogeneous plasma (Srivastava and Vyas, 1979).

The oscillations of a capillary jet of infinite electrical conductivity in the presence of a uniform axial magnetic field have been investigated by Kamla, Abani and Srivastava (1978). In the inviscid case the wavelengths are increased due to magnetic field the reverse being the situation with viscosity.

The energy content has been estimated of extragalactic sources taking into account the interaction of intense low frequency electromagnetic beams with a plasma (Krishnan, 1979).

An instability model is suggested by Krishnan (1980) to account for the generation of electromagnetic frequencies near

the electron plasma frequency. This model explains the generation of Type III solar radio bursts.

Propagation in Inhomogeneous Plasmas

The plasma processes encountered in the ring current and plasma sheet region are studied in detail by Bhatia and Lakhina (1978 *a*, *b*). For instance, the drift cyclotron instability near proton cyclotron frequency is shown to generate wavelengths in the range of 1–100 times the electron Larmor radius. The quasi-electrostatic drift loss cone instability on the otherhand is shown to cause precipitation of protons in the auroral regions leading to a diffused aurora (Bhatia and Lakhina, 1980 *b*, *c*). Further, the presence is explained of electrostatic proton cyclotron waves in the auroral field lines as well as of ULF waves on the dayside magnetosphere by involving antiloss cone instability mechanism (Bhatia and Lakhina, 1980 *a*).

The excitation of whisler mode in the solar wind at a distance of a hundred solar radii is investigated by Revathy (1978 *a*, *b*) to explain the α-particle heating and their acceleration. Also, the beam cyclotron instability and electron acoustic instability driven by cross tail current and inhomogeneity in density and magnetic field are found to cause anomalous resistivity in the earths magnetic tail region (Nayar and Revathy, 1978).

The tangential discontinuities at the magnetospheric boundary and the instabilities arising due to these have been studies by Rajaram (1978) and Rajaram *et al.* (1978, 1980).

The non-linear evolution of an electron beam magnetoplasma system is studied in order to interpret the characteristics of type IIIb solar radio bursts by Krishnan *et al.* (1980).

The spiral structure exhibited by most of the disk galaxies is successfully explained in the framework of density waves which arise due to plasma accretion by Ambastha and Varma (1978).

Basic Processes of Wave generation and Nonlinear Phenomena

Experiments are being carried out on the propagation of relativistic electron beams through a cusp by Jain *et al.* (1980) using a gas injected washer plasma gun.

The propagation characteristics of ion-acoustic solitons in plasmas having sharp density gradients have been studied by Dahiya *et al.* (1978). A reflected wave packet is observed as a soliton encounters a sharp density gradient (Karney *et al.*, 1979).

In a theoretical work by Sen *et al.* (1978), the sustenance of solitary waves is shown with a constant amplitude and width at the cost of two dimensional depletion of the lower hybrid waves. Further, the influence of a random spectrum of lower hybrid waves on the evolution of tearing modes have been shown to enhance significantly the growth rates (Sundaram and Sen, 1980 ; and Sundaram *et al.*, 1980).

The nonlinear wave characteristics particularly of ion-acoustic and drift waves have been investigated by Buti (1978*a*) and by Mohan and Buti (1978, 1979) in order to explain the turbulence observed in the solar wind and interplanetary space. The effect of hot and cold ions on the evolution of ion and electron acoustic waves is investigated in the presence of single and multiple level electrons (Buti *et al.*, 1980 ; Mohan and Buti, 1980 ; Buti, 1980 *a*, *b* ; and Sharma and Buti, 1978). The width of the solitary waves is found to be reduced substantially due to the multiplicity of enemy levels of the electrons.

The effect of stochastic magnetic folds on the plasma waves have been investigated (Mittal and Prahalad, 1978 ; Prahalad and Mittal, 1978, 1980 ; Mittal *et al.*, 1980 ; and Prahalad *et al.* 1980). The excitation and damping of different normal modes of the plasma have been shown to occur due to phase mixing and the three wave process.

The anomalous conductivity induced due to ion acoustic turbulance has been investigated by Krishnan (1978). The importance of wave particle interaction, scattering on density fluctuation and energy renormalisation are studied.

Waves generated in space

The new mechanism for pulsar radiation is suggested by Buti (1978 *b*) involving the generation of relativistic Langmuir solitons in the magnetosphere of the neutron star.

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COMMISSION J

RADIO ASTRONOMY

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1. New Instrumentation and Techniques

The stability and sensitivity of the Ooty Radio Telescope have been improved by (i) installation of a new dipole array employing low-loss diode phase-shifters and (ii) increasing the system bandwidth from 4 MHz to 12 MHz. Two of the seven remote antennas of the 4 km synthesis radio telescope at 327 MHz have been completed and used for observations, while a third antenna, (a cylindrical paraboloid of dimensions 9 m 25 m) is nearing completion. For controlling and monitoring the remote antennas of the synthesis telescope, digital telemetry on a VHF link has been developed and installed. Also, a digital delay-multiplier unit has been built to correlate signals from the different antennas. A PDP-11/70 computer system is now available for on-line control and monitoring of the synthesis telescope as well as off-line data processing. Hardware and interfaces required for controlling the synthesis telescope and the Ooty Radio Telescope have been built and the necessary software developed.

A receiver system at 327 MHz has been designed and built for the parabolic antenna of the University of Nigeria for observations on pulsars and for use in a collaborative programme of very long baseline interferometry between the Nigerian telescope and the Ooty Radio Telescope.

A 128 channel autocorrelation receiver has been commissioned by the Raman Research Institute, Bangalore for observations of hydrogen recombination lines at around 327 MHz using Ooty Radio Telescope. The bandwidth of the spectro-

meter can be selected as 125 kHz or 250 kHz or 500 kHz. A 40 channel 1-bit autocorrelator has been developed at the Physical Research Laboratory, Ahmedabad for use in the study of interstellar hydroxyl molecular emissions. Two sets, one of 7 and the other of 50 minutes of integration time, of test observations were analysed to compute autocorrelation functions and power spectra (Alurkar *et al.*, 1980). Two of the stations (Ahmedabad and Rajkot) of the three station IPS observatory of the Physical Research Laboratory are operational now (Alurkar *et al* , 1981) and preliminary results of IPS observations of strongly scintillating sources have been reported (Alurkar and Bhonsle, 1980). The third station at Surat will become operational by the end of 1981.

A multibeam scanning system has been incorporated in the NS array of the Decameterware Radio Telescope (Sastry, 1980) at Gauribidanur which is being operated jointly by the Indian Institute of Astrophysics and the Raman Research Institute, Bangalore. The scanning system automatically points the beam in succession to eight declinations anywhere in the range -30 to $+60$. The fastest rate of scanning is ten times per second. The receiver output at each of the eight declinations is available in both analog and digital form. A 16-channel receiver for high time and frequency resolution observations of radio bursts from the Sun and Jupiter has been built. The centre frequency of this receiver can be set anywhere in the range 25 to 35 MHz. The channel separation is 50 kHz and the bandwidth of each channel is 10 kHz. The time resolution is 20 milliseconds. A two channel scintillometer for measuring the scintillation index of sources which exhibit IPS is also incorporated with the Decameter array. The equipment measures total and scintillating fluxes of sources. A band pass filter in the range 0.1 to 1.5 Hz is used to select the fluctuations which are squared and smoothed to give the scintillating flux. IPS observations on several sources are being made on a synoptic base both for the study of the structure of sources and the interplanetary medium.

A new method of deconvolution called "Optimum Deconvolution Method" (ODM) has been developed and applied to the analysis of lunar occultation observations (Subrahmanya, 1979,

1980*a*). This method is essentially a generalised least-squares procedure but is adapted to conform to *a priori* information and provides an optimum solution to the problem. The main feature of the method is a simple iterative algorithm for incorporating positiveness of the brightness distribution. The method provides an improvement in resolution by a factor about 1.5 to 2 over the conventional methods. Image reconstruction methods in radio astronomy have been reviewed (Subrahmanya, 1980*b*).

The maximum entropy method (MEM) of spectral analysis is examined from a somewhat novel view point (Komesaroff *et al.*, 1981) in terms of autocorrelation sequences and sequence of unit vectors. Positivity constraint is automatically ensured by setting the unspecified autocorrelation terms within a "circle of constraint". The MEM is shown to be a type of model fitting; the model consisting of a number of asymmetric peaks equal to the number of autocorrelation terms originally specified. The effect of measurement errors is shown to make the spectrum more peaky since the "circles of constraints" are forced to contract to points.

A workshop to discuss the proposals made by G. Swarup (India), T. R. Odhiambo (Kenya) and S. E. Okoye (Nigeria) for the establishment of an International Institute for Space Sciences and Electronics (INISSE) and the construction of a Giant Equatorial Radio Telescope (GERT), with a collecting area an order of magnitude larger than that of the Ooty Radio Telescope, as a collaborative effort among the developing countries was held at Ootacamund, India during April 1979 with financial support from UNESCO, Department of Science and Technology of the Government of India and the Commonwealth Foundation. It was attended by participants from Egypt, India, Indonesia, Iraq, Kenya and Nigeria. A representative of UNESCO was also present. In addition, two distinguished radio astronomers, Professor W. N. Christiansen (Australia) and Professor A. Hewish (United Kingdom) attended the workshop as consultants to UNESCO. The proposed projects received unanimous support from the participants and the consultants.

Solar decameter bursts of type IIIb have been observed with high time and frequency resolution at a centre frequency of 25 MHz and their time structure were determined (Sastry *et al.*, 1980 ; and Krishnan *et al.*, 1980). A theoretical model which accounts for various aspects of these bursts is proposed in terms of the interaction of an energetic electron beam passing through a stationary plasma along the magnetic field lines in the solar corona.

Two dimensional brightness distribution across the Sun of the slowly varying component at decameter wavelengths has been determined (Sastry *et al.*, 1981). Correlation between exciter duration and decay constant of solar decameter Type III radio bursts has been investigated (Subramanyan *et al.*, 1981). Pulsating radio emission from the Sun (Sastry *et al.*, 1981) and time structure of drift pair radio bursts from the Sun (Subramanyan and Sastry, 1981) at decameter wavelengths has been observed and studied.

From the occurrence of a microscopic "U" burst simultaneously with a type IIIb burst, the length of the exciter beam of the order of 10^3 km and fine structure in the electron density irregularity at two solar radii above the photosphere have been estimated (Sawant *et al.*, 1978*a*). A model for the generation and propagation of solar decametric bursts associated with noise storm activity is given. From the analysis of microscopic burst, electron density irregularities and their sizes have been estimated (Sawant *et al.*, 1978*b*). New microscopic burst features called "echo-like" bursts have been observed. These bursts can be explained if the same electron density irregularity in the corona is excited into plasma oscillations by two successive exciters and the irregularities move with velocities ranging from 100 to 1000 km/s near two solar radii from the photosphere (Bhonsle *et al.*, 1978). Evidences for mass ejections from flaring regions are seen. A shock wave generated during the flare travelled in a transverse direction with 500 km/s and so no type II burst was seen (Bhatnagar *et al.*, 1978).

Current state of knowledge of high resolution at decameter wavelengths of the quiet sun, the slowly varying component,

type I to V bursts and noise storms has been summarized. It is shown how the observations have yielded important physical parameters of the solar corona, at 1 to 2 solar radii above the photosphere. Information on angular sizes of noise storm sources, all the known varieties of decametric bursts, polarization of bursts and continuum and important features of models of noise storms have been reviewed (Bhonsle *et al.*, 1979).

Measurements of solar microwave flux at four frequencies were made near Hyderabad during the total solar eclipse on 16 February 1980. Residual fluxes and brightness temperatures were determined (Bhonsle *et al.*, 1980).

An impulsive microwave burst of September 19, 1977 did not have corresponding hard X-ray burst showing gradual rise and slow decay profile (Degaonkar *et al.*, 1980).

Complementary bursts (C. B's) were discovered in the decameter range by using high resolution spectroscope at 35 MHz. These bursts essentially consist of two components with short duration of about one second but the second component is delayed with respect to the first one by a few seconds. The frequency range of the second component is about equal to that of the emission gap in the first component. If the bursts are assumed to be generated at fundamental and if the radiation corresponding to the gap propagates through an electron density irregularity located close to the source and whose cross-section is less than the linear extent of the source, then almost all properties of C. B's can be explained (Sawant *et al.*, 1980*a*).

From the observed intensity variations in type II bursts over a time scale of a few seconds, the shock thickness has been estimated to range from a few hundred to a few thousand kilometers (Sawant *et al.*, 1980*b*). From the observed low frequency cut-off in type IV solar decametric continuum and interpreting it as Razin effect, a coronal magnetic field of 6 gauss at about 1 solar radius above the photosphere has been estimated (Bhonsle and Degaonkar, 1980). This is the first evidence of Razin effect observed in the decametric range.

3. Extragalactic Radio Astronomy

Lunar occultation observations with the Ooty Radio Telescope have continued to provide accurate positions and brightness distributions with resolutions of the order of a few arc seconds. Results for an additional 500 sources were published (Subramanya and Gopal-Krishna 1979 ; Singal *et al.*, 1979 ; Venkatakrishna and Swarup 1979 ; and Joshi and Singal 1980). Searches in the optical fields of these sources on the Palomar Sky Survey prints have enabled about 25 per cent of them to be optically identified. The data have been used in a number of investigations concerning models of extragalactic radio sources and observational cosmology.

Occultation data on 15 radio sources associated with rich clusters of galaxies has shown that a majority of such sources are resolved. Two sources were found to have a head-tail radio structure and is believed to arise from the rapid movement of the associated galaxy through the cluster medium (Singal *et al.*, 1980).

High resolution studies based on occultation observations have been made for 10 optically selected bright galaxies (Gopal-Krishna 1978*c*). Of the 5 spiral galaxies radio output of only NGc 4433 seems to be dominated by thermal emission. Overall radio extents of 4 of the 5 E/SO galaxies were comparable to their optical dimensions. Four of the 10 galaxies appear to be members of dynamically interacting galaxy pairs and show an additional discrete radio source lying at a projected separation of $\leqslant$ 5 arcmin ($\sim$ 1000 kpc).

From an analysis of the observed counts of extragalactic radio sources at meter and centimeter wavelengths and their spectral index distributions a Generalized Luminosity Function (GLF) has been derived (Kulkarni, 1978). The GLF describes the comoving space density of extragalactic radio sources as a function of radio luminosity, spectral index and redshift. A study of the angular size-redshift relation for radio sources by taking into account the possible evolution of individual sources indicates that it may be possible to explain the observed relation without postulating a change in the overall linear size of double sources with Cosmic epoch (Saikia and Kulkarni, 1979).

A sample of double radio sources has been examined to

test for a correlation between the prominence of compact hot-spots located at their outer edges and membership of clusters of galaxies. Sources in clusters of galaxies are found to have less prominent hot-spots. This result has been shown to be consistent with the continuous flow models of radio sources but poses problems for the gravitational slingshot model (Saikia, 1979).

A study of the evolution of double radio sources associated with galaxies and quasars has been made by comparing the ratio of angular separation of the two lobes from the central object and the ratio of flux densities of the two lobes for the known strong radio sources with the corresponding ratios for the weaker Ooty occultation sources. The results indicate that the average velocity of separation of the individual components of a double source could be a significant fraction of the velocity of light and the luminosities of components may decrease quite rapidly with age. Alternatively, the observation may suggest that the Intergalactic medium is not uniform (Swarup and Banahatti, 1980 ; and Banahatti, 1979).

It is shown that the differential bending of radio waves by an intervening galaxy can give rise to apparent super-luminal separation of radio components in the nuclei of quasars (Chitre and Narlikar, 1980).

4. Galactic Studies: Continuum, Pulsars and Stars

Planetary Nebulae

Lunar occultation of four planetary nebulae indicate that these sources have a thermal spectrum and that the derived angular size at 327 MHz is consistent with the optical size (Gopal-Krishna 1978*a*).

Flare Stars

The analysis of the simultaneous optical and radio observations at 327 MHz of flare stars in the Pleiades region undertaken in collaboration with USSR scientists has not revealed any flares during five intense optical fiares (Sanamian *et al.*, 1978).

Pulsars

Interstellar Scintillation (ISS) observations of 28 pulsars in the dispersion range 5-110 pc cm^{-3} were made with a bank

of 12 narrow bandwidth receivers and a method was developed for separating the effects of intrinsic variations from those of ISS. Results indicate the existence of intrinsic variations, with time scales similar to those due to ISS, in most pulsars (Balasubramanium and Krishnamohan, 1978). A search for pulsars using a multichannel receiver was initiated leading to a discovery of 2 pulsars (Mohanty and Krishnamohan, 1978).

Lunar occultation observations of the pulsar 0950+08 have revealed the presence of a halo of nonthermal emission with an east-west extent of $\sim$ 1 arcmin and a flux density of 0.2 ± 0.1 Jy at 327 MHz (Gopal-Krishna, 1978*b*). It could be the 'ghost' remnant theoretically postulated to form around an old pulsar as a result of confinement by the interstellar medium of low energy electrons escaping from the pulsar.

The polar cap model and the relativistic beaming model for pulsars predict different tracks for drifting subpulses in the longitude versus pulse number diagram. By using the observations of the pulsar PSR 0031-07, it was shown that they conform better to the prediction of the relativistic beaming model than to that of the polar cap model (Krishnamohan, 1980).

The correlation between pulsar proper motions and radio polarisation data has been used to find (Morris *et al.*, 1978) the association between pulsars and supernova remnants. The associations proposed on this basis are faced with discrepancies in the ages of the pulsars and supernova remnants which may be resolved by assuming that pulsars are born in close binary systems.

The possible role of the diffuse background gamma radiation in triggering the polar gap discharges in pulsars has been examined (Radhakrishnan, 1980). It was concluded that the number of charges produced in the gap per second by the above mechanism should suffice to sustain pulsar action, provided the surface magnetic field strength of the neutron star lies between 1×10^{12} and 2×13^{13} gauss. The implications of the above picture for the evolution of supernova remnants has been studied (Radhakrishnan and Srinivasan, 1980*b*) leading to the conclusion that neutron stars which function as pulsars will be associated with filled remnants while those which do

not function as pulsars, but which emit dipole radiation will produce shell type remnants.

Several extended supernova remants and HII regions have been mapped (Dwarakanath and Sastry, 1981) at decameter wavelength using Gauribidanur telescope.

5. Galactic Studies: Spectral Lines

Detection of the ground state hyperfine transition of deuterium at 327 MHz in absorption towards Galactic Centre has been undertaken (Sarma and Mohanty, 1978) using Ooty Radio Telescope leading to (Anantharamaiah and Radhakrishnan, 1979) a new upper limit of 5.8×10^{-5} for the atomic D/H ratio. This upper limit is compatible with the direct measurement of the D/H ratio in nearby interstellar clouds from UV observations by the Copernicus satellite.

A gaussian analysis of the HI absorption spectrum of Sgr A obtained with the Parkes Interferometer has yielded (Radhakrishnan and Sarma, 1980) a reliable estimate of the peak optical depth of 4.6 at zero velocity and a new determination for the external motions of interstellar clouds of $\sigma = 4.8$ kms^{-1}. In addition it has revealed the presence of a very wide, dispersion of 35 kms^{-1}, and low optical depth, $T = 0.3$, absorption feature also centred around the zero velocity. Both the narrow and wide components have mean velocities differing from zero by less than 0.25 km $^{-1}$, thus confirming the standard value of the solar motion and contradicting galactic models which postulate a radial motion of the local standard of rest. It has been proposed (Radhakrishnan and Srinivasan, 1980*a*) that the wide feature is due to a new population of hot clouds, spin temperatures around 300K, found presumably inside supernova bubbles, whereas the standard cold clouds are found in the region in between old supernova remnants. It was estimated that the hot clouds contain twice the amount of hydrogen and a hundred times the kinetic energy of the cold clouds.

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